MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF OCEAN ENGINEERING
CAMBRIDGE, MASS. 02139

September 10, 1980

Annual Technical Report On

THE PREDICTION AND MEASUREMENT OF
DYNAMIC PROPERTIES OF OFFSHORE STRUCTURES

J. Kim Vandiver
Associate Professor
Principal Investigator

Reference Contract No. 14-08-0001-17202

Annual Technical Report on

THE PREDICTION AND MEASUREMENT OF
DYNAMIC PROPERTIES OF OFFSHORE STRUCTURES

J. Kim Vandiver
Principal Investigator

Introduction

This research program began three years ago. The fundamental objective
of the research is to extend the understanding of the dynamic response of
offshore structures. This general objective is focused on two prominent goals.

1. The accurate determination of structural dynamic response
   properties, such as natural frequencies, damping and mode
   shapes, from data collected in the field.

2. The prediction of the dynamic response of offshore structures
   to wave excitation.

The two topics are closely related. The work has been and will continue to
be a carefully coordinated effort combining the continued development of
spectral analysis methods for estimation of dynamic response properties with
the development of prediction models and model testing procedures for
estimating the dynamic response level of a structure in a specified sea state.
Data collected on full scale structures and models are used in the research.

The results have immediate application in the offshore industry.
Improved methods for natural frequency and mode shape identification are
required to make integrity monitoring a viable inspection tool. At the May
1980 Offshore Technology Conference numerous papers were given on field
experience related to structural integrity monitoring. The general concensus
was that damage detection based on vibration signature analysis will require
monitoring of local modes with transducers located below the water line. On
individual members, positive mode identification is hampered by the coupling
of response to modes of similar natural frequencies on nearby members. The
spectral analysis research proposed here is applicable to such problems.

The response prediction research is especially applicable to the problem of fatigue life prediction. Fatigue has become one of the controlling design issues for new structures in deep water, because such structures have natural periods corresponding to quite energetic regions of daily occurring wave spectra. Under such circumstances the dynamic amplification of response at the natural periods of the structure is critically dependent on damping. The importance of our current research on damping estimation from measured response data has already been recognized by the offshore industry. Damping prediction on future structures is also an important issue in fatigue estimation. Our current and proposed research in this area is very timely. With the advent of high oil prices the industry has begun to turn to reservoirs in shallow water which have in the past been uneconomic to produce. Low cost lightweight structures such as simple caissons are being considered for location of single wells. These structures have substantial dynamic response, and are prone to fatigue. Our present and future research is very appropriate to understanding such structures.

The remainder of this report is divided into two parts, one for each of the principal thrusts of the research. In each case a brief summary of the accomplishments to date will be presented.

Dynamic Response Prediction

Results to Date

The results of our earlier research on the prediction of the dynamic response of an ocean structure to linear wave forces was presented at the 1979 Offshore Technology Conference, and later reviewed and published in The Society of Petroleum Engineers Journal in February 1980 [1]. A copy of that paper is included in the appendix. Linear wave force models are appropriate on structures with large members such as tension leg platforms. The past research revealed analytically that for such structures it would be possible to measure directly on a model the wave amplitude to wave force transfer function as a function of wave incidence angle and frequency. In practice the model would be held rigidly in place by load cells which would measure directly the heave, surge, and sway modal forces and the pitch and roll

exciting moments. Linear theory shows that such transfer functions can be used directly to predict the individual modal responses in directionally spread random seas. Theory also shows that such measurements may be used to directly compute the modal radiation (wave making) damping components.

A major effort of this year's research was experimental verification of the linear theories. To this end a model of a tension leg platform was borrowed from a major oil company. The modal exciting forces were measured in the towing tank as a function of wave frequency and incidence angle on the structure. The results were compared to those predicted independently by an industry owned computer program. The agreement was very good. The major objective of the experiment was achieved: the verification of a new model testing procedure for direct measurement of modal exciting forces. These measured transfer functions when combined with the linear response prediction theory previously published provide a new and comparatively inexpensive response prediction tool. Furthermore, because the model is held fixed in place, many dynamic scaling laws need not be satisfied. For example, for a TLP it is not necessary to model the water depth, tension cables, or system natural frequencies exactly, as would be required in a conventional dynamic response model test. Industry interest and support is indicated by the loan of the model and by the donation of a small amount of funds to upgrade our model testing facilities.

The preceding results all depended upon the assumption of linearity of wave forces. Such an assumption is only valid when the wave amplitudes are less than the diameter of typical structural members. This is often not the case offshore and it may be often necessary to include the non-linear relationship which accounts for fluid dynamic drag forces. A goal of the current research was to develop a frequency domain response prediction technique which would include the separated flow non-linear drag forces. The results of this research comprise the bulk of an outstanding Ph.D. dissertation which was completed and defended on May 19, 1980 [2]. The results were presented in two short seminars at Shell Development and Exxon Production Research during the May 1980 Offshore Technology Conference (OTC), and also at the Technical University in Trondheim, Norway, in June, 1980. The work was well received. The results not only provided a frequency domain prediction of response including non-linear drag effects (a first), but also established the relationship

between viscous damping and sea state -- an extremely important achievement which bears heavily on fatigue life prediction.

A copy of the Ph.D. dissertation is enclosed with this report. The results are presently being condensed into a technical paper intended for presentation at an international hydrodynamics conference to be held in August 1981 in Trondheim, Norway.

The first opportunity to field test our linear and non-linear response prediction theory became available a few months ago. Amoco agreed to allow us to conduct a field measurement program on a simple caisson (vertical cylinder cantilevered from a bottom pile support). The caisson supports a single gas well. It has a natural period of 3.1 seconds, which is like very deep jackets such as Cognac and Hondo. The caisson also has a diameter of four feet which is typical of the cylindrical members on deep structures. The very simplicity of the caisson makes it possible to establish the wave amplitude to dynamic response transfer function much more accurately than could be accomplished on a large complex structure. One week was spent in the field. Amoco provided all necessary logistic support and placed no restrictions on our publication of data. We returned with an excellent data base including wind, wave and response records in a variety of weather conditions. The data base will be used extensively in our next year's work.

Identification of Dynamic Response Properties

Results to Date

Our effort has focused on the application of the Maximum Entropy Method of spectral analysis to the problem of natural frequency and damping estimation. Brad Campbell completed his Ph.D. dissertation on this subject in December 1979, and presented the results in a paper at the 1980 OTC [3]. The estimation of total damping of a structural natural mode from ambient acceleration response time histories was the principal emphasis of the research. The results were very good. For the first time, damping estimates were made for the natural modes of offshore structures in a manner that included estimates of the confidence bounds. The MEM damping estimates were compared to results measured by Al Ruhl of Shell, using forced excitation. The results

-4-

agreed to within the confidence bounds specified by the MEM results. These
methods are sufficiently accurate that it is possible to measure the effect
of sea state on damping -- an important relationship which has been previously
unobtainable. A copy of the 1980 OTC paper is included in the appendix of
this report. This paper has been reviewed and is scheduled for presentation
at the 1980 Winter Annual Meeting of ASME and will also be published in a
future issue of an ASME Journal. This work was also presented in June 1980
at Det norske Veritas in Oslo and at the University in Trondheim.

It was initially intended that multiple channel MEM techniques would
be applied to the mode shape identification problem, during the present con-
tract year. This has not been done, for the following two reasons. First,
the single channel MEM damping estimator work was expanded to include the
estimation of confidence bounds, which at the time of last year's proposal
was thought to be impossible. Second, the rather sudden opportunity to con-
duct the caisson field test was too good to pass up. The structure was
scheduled for substantial modification this summer, which will render it
useless for experimental work. Of course, this redirection of effort was
documented in previous correspondence, and approved by the technical monitor
of the contract.

Future Work

Mode shape identification through the use of multiple channel MEM tech-
niques remains a promising area for research, with the results being appli-
cable to structural integrity monitoring technology and to design verification
through comparison of design predictions of dynamic response to later field
observations. The issue of design verification was cited at the recent OTC
as being one of the important spinoffs of the integrity monitoring research.
Better understanding of the basic structural dynamics is viewed as a signifi-
cant achievement in the industry.

It is intended that the multiple channel MEM research be completed in
the next year. One of the promising uses of the multiple channel MEM work
was discussed at the 1980 OTC with Mr. Ben Burke of Chevron. He presented a
paper on mode shape identification using a method known as "Response vector

analysis" [4]. It appears that this method may be improved significantly by combining it with MEM spectral analysis techniques. It was agreed at OTC to cooperate on the unification of the two methods in the coming year.

It is intended that in the coming year two additional topics relevant to response measurement be investigated. The research is of a preliminary nature, intended to identify promising avenues of future research. The first bears directly on integrity monitoring of local modes. The concensus of the investigators present at OTC suggests that local member monitoring is the way of the future. Limited empirical data is available at this point, and no analytic studies of any merit have been performed. A timely analytic look at proposed local monitoring techniques may identify pitfalls. Two examples of potential problems that direct analysis can shed light on are: the potential smearing of local mode response spectra due to axial load variation, and sound radiation damping of local modes. The latter is especially relevant to the use of damping as an indication of damage.

The second topic for preliminary investigation is a variant of MEM analysis. MEM is also known as an autoregressive (AR) estimator. Similar methods known as autoregressive moving average (ARMA) techniques may be especially useful in the estimation of transfer functions such as wave amplitude to wave force or structural response. The evaluation of such transfer functions from experimental data is very difficult and this preliminary work may indicate directions for beneficial future research.

References

[1] Vandiver, J. K., "Prediction of the Damping-Controlled Response of Offshore Structures to Random Wave Excitation", Society of Petroleum Engineers Journal, February 1980.

[2] Dunwoody, A. B., "The Role of Separated Flow in the Prediction of the Dynamic Response of Offshore Structures to Random Waves", Ph.D. Dissertation, M.I.T. Department of Ocean Engineering, May 1980.

[3] Campbell, R. B., "The Estimation of Natural Frequencies and Damping Ratios of Offshore Structures", Ph.D. Dissertation, M.I.T. Department of Ocean Engineering, January 1980, presented at the 1980 OTC, Paper OTC 3861, Houston, May 1980.

[4] Burke, B. G., "Characterization of Ambient Vibration Data by Response Shape Vectors", Standard Oil Co. of California, with C. Sundararajan and F. M. Safaie, Keith, Feibusch Associates, Engineers, Proceedings of the 1980 OTC, Paper No. OTC 3862.